Oct. 7, 1958 F. S. ROHATYN 2,855,576

TRANSFORMERS

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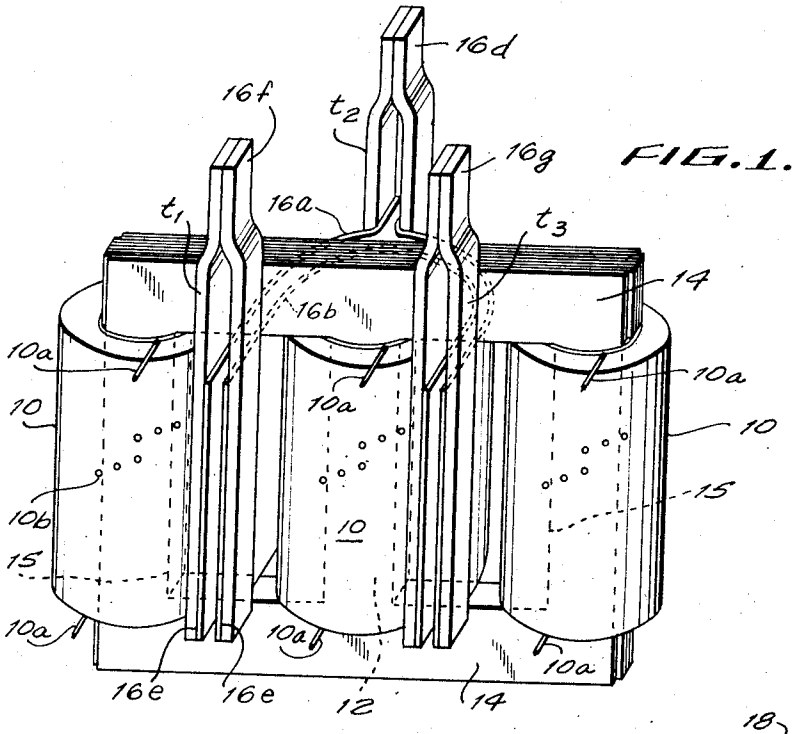


FIG. 1.

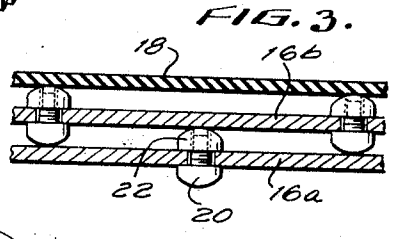


FIG. 3.

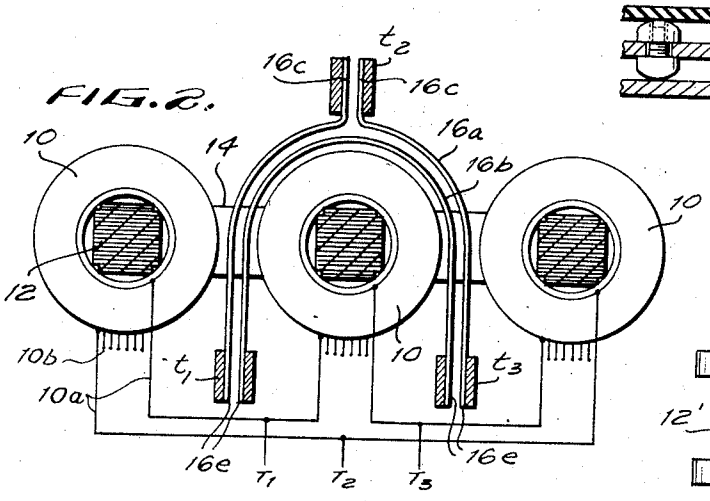


FIG. 2.

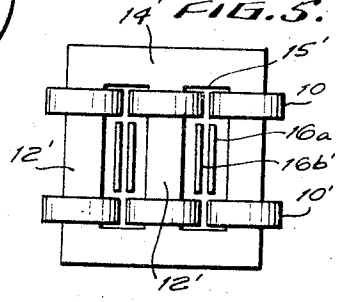


FIG. 5.

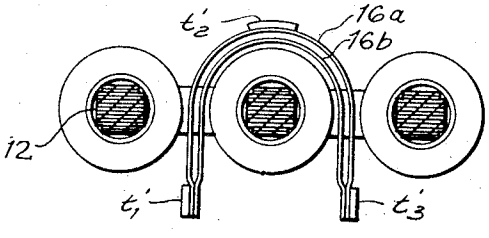


FIG. 4.

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TRANSFORMERS

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19 Claims. (Cl. 336—182)

The present invention relates to polyphase transformers. The following specification is drawn particularly to step-down three phase transformers having delta-connected secondaries although other applications of the broader aspects of the invention will be apparent from the disclosure. In another aspect, the present invention relates to the cooling of transformer windings.

Various types of three-phase transformers have been used for supplying high-current loads at comparatively low voltage from high-voltage power lines. One common type involves a core with a plurality of separate windings stacked each upon the next and in which the three phase primary and secondary windings are interleaved. This type of construction is of special advantage in making readily available a series of taps on each primary winding without obstruction from the other windings. Also, it facilitates connection of any number of single-turn coils in parallel.

This type of construction has the prominent disadvantage of developing high mechanical axial stresses under short-circuit conditions. The mechanical resistance to short-circuit stresses requires a strong mechanical design, and this, in turn, results in high cost in labor and material, and in a heavy, bulky structure. The cooling is inherently poor, or difficult to accomplish in dry-type transformers of this type, so that the interleaved transformer is almost always of liquid-immersed construction.

Instead of the interleaved coil construction, another less-used form of construction in this field of service is the concentric winding type. The high-voltage primary windings in concentric transformers usually are inside the secondary windings in order that the heavy low-voltage leads or busses of the secondary may be readily accessible. For high current capacity the secondary is of only a single turn and in order to develop the desired high current capacity several parallel straps are sometimes used or the low voltage winding is formed of a single sheet or laminated cylindrical sheets of suitable thickness.

These transformers are less bulky than the interleaved type described above and can be designed to avoid the axial short-circuit stresses of the interleaved form of construction. Additionally, the concentric type of transformer can be designed for effective air cooling and therefore dry-type construction can be used.

An important disadvantage of the concentric type of transformer described is the non-accessibility of the taps of the primary winding within each low voltage coil. Ordinarily the taps are taken via axially extending connections extending along ducts, and this raises fabricating difficulties because of obstructing ducts and represents a source of trouble in operation. It is probably for this reason that the concentric type of three phase step-down transformer is generally in disfavor even though it is less bulky than the interleaved type.

An object of the present invention is to provide a new and improved form of transformer construction. A further object is to provide a new form of polyphase transformer that is much lighter in weight than conventional comparable transformers. A further object is to provide a transformer combining advantages of both of the aforementioned types of step-down transformer construction and eliminating certain disadvantages of both. A further object of this invention is to devise a three phase transformer of the concentric type in which the terminal connections for the primary and secondary windings are unobstructed by any of the windings. An additional object is to provide a three phase step-down transformer, particularly of the concentric type, wherein a variable ratio is available by virtue of a series of primary taps extending radially from the various primary windings despite the provision of a secondary winding outside the primary windings.

The foregoing objects are of considerable importance in improving the reliability and reducing the cost, weight and bulk of previously known transformers having low-voltage, high current windings. A transformer incorporating novel features of this invention has the further advantage of enabling multiple parallel branches to several parallel loads, where the connections are made straight to the transformer windings. A generally U-shaped low voltage winding with terminals at the midpoint and at the extremities of the U is included in each of the three-phase embodiments of the present invention detailed below. In a further aspect, the invention provides a novel, effectively cooled low-voltage structure of the type made of comparatively broad sheets of conductor. The invention will be better appreciated and further features of novelty and aspects of the invention will be apparent from the following detailed description of several illustrative embodiments. In the drawings:

Fig. 1 is a somewhat diagrammatic perspective view of an embodiment of the present invention;

Fig. 2 is a horizontal cross-section of the embodiment in Fig. 1;

Fig. 3 is an enlarged detail, in cross-section, of the secondary structure of Figs. 1 and 2;

Fig. 4 is a cross-section similar to Fig. 2 of a modification of the embodiment of Figs. 1 and 2; and

Fig. 5 is an elevation of a further embodiment of the invention.

In Figs. 1 and 2, a novel transformer structure is illustrated, of excellent properties in respect to reduced bulk, and accessibility of the primary winding for making variable voltage taps and for efficient cooling. This transformer structure includes concentric primary and secondary windings. The core structure of this transformer includes end portions **14** that bridge three parallel legs **12** of equal cross-section about which the primary windings **10** are disposed. A window **15** is formed between each pair of core legs **12**, and two of the three primary windings extend through each window. Each primary winding is seen to have a pair of terminals **10***a* and in addition, a series of variable voltage taps **10***b* extending radially from the outer surface of that primary winding so as to be readily available and accessible for any desired connection. As shown in Fig. 2, the primary terminals are connected in delta, although Y-connection is equally feasible with the primary terminals available.

The secondary winding is disposed about the center primary winding, and, as illustrated, is in the form of a pair of U-shaped sheets **16***a* and **16***b* of copper or the like nested one within the other and spaced apart for cooling. Outer sheet **16***a* preferably is divided at its midpoint to incorporate a terminal t_2, whose construction is described in detail below. Each sheet may be subdivided into layers or laminations, and these may be spaced apart for cooling. The extremities of these U-shaped sheets are joined together in a manner detailed

below to provide terminals t_1 and t_3. These terminal bars as shown are extended endwise for connection to a load, and the terminal bars are split lengthwise as shown in Fig. 1 for reducing eddy currents. The secondary structure should be electrically centered along the primary, axially, to minimize axial mechanical stresses in the event of short-circuiting. This is easier to accomplish in this type of transformer than in any other known.

By virtue of this arrangement, a delta-connected low voltage secondary winding is provided. Suitable mechanical support (not shown) is arranged to fix the secondary winding in relation to the primary winding on the central leg or bar portion **12** of the core, and about the primary winding **10** on that central bar **12**. Each of the windings is appropriately insulated from the core legs and the bridging end portions of the core. One phase of the secondary is found between the terminals t_1 and t_2, along sheet **16***a*, extending through one window **15**; a second phase is found along sheet **16***a* between terminals t_2 and t_3, extending through the other window **15**; and the third phase of the delta is found along sheet **16***b* between terminals t_1 and t_3, extending through both windows. If an open-delta secondary is desired, sheet **16***b* may simply be omitted, and the cross-section of the remaining sheet may be increased if necessary for adequate current capacity. The delta connection shown is of advantage (among other advantages) in more perfect balance of internal impedances.

A variable-ratio primary-to-secondary three phase transformer is here provided in which the taps of the primary winding are completely free and need not be taken out axially in ducts as in the case of known forms of concentric-secondary transformers, in which the secondary is disposed outside the primary winding. This construction minimizes the stresses occurring during short circuiting of the secondary, and as a result the bulk and weight of the supporting and mechanical integrating structure for the transformer is minimized, and the cost of assembly of the transformer is vastly reduced. Multiple loads can be connected to the secondary winding in parallel or separate U-shaped secondaries may be arranged one within another for respective loads. By avoiding three complete secondary windings about each leg **12** of the core, not only is there vast simplification of the terminal connections, but the copper needed for the secondary is greatly reduced.

The terminal construction of the secondary illustrated by Figs. 1 and 2 is of detailed significance. The outer sheet **16***a* of the double-walled U is seen to be split at its midpoint so as to have outwardly directed flanges **16***c*, and these are separated a short distance and they are joined to respective vertically extending terminal bars t_2 that are joined to each other at a point **16***d* distant from the major stray fields in the region of the windings. The edges **16***e* of the double-walled U, that is, the extremities of sheets **16***a* and **16***b*, are spaced apart and are provided with terminal bars t_1 and t_3 joined in pairs at respective points **16***f* and **16***g* remote from the major stray fields present in the immediate proximity of the windings. The physical separations between the three conductive-sheet portions of the secondary, t_1 to t_2, t_2 to t_3, and t_3 to t_1, are of practical importance in that they reduce eddy currents that might otherwise be excessive in a high power transformer.

The conductive sheets which form the U structure should naturally be of a cross-section that is suitable for the current rating of the secondary, bearing in mind the limitations on cooling such a transformer winding. Similarly, the terminal bars should be of appropriate cross-section for the transformer rating. These terminal bars need not equal the cross-section of the sheets **16***a* and **16***b*, because such terminal bars are freely exposed for effective cooling. The areas **16***c* and **16***e* where the physical connection is made between each conductive sheet and each terminal bar should be extensive to minimize heating that might otherwise occur at such a joint; and similarly, the terminal bars are joined to each other in connections **16***d*, **16***f* and **16***g* of appropriately large area.

The conductors forming the secondary are effectively cooled through the provision of a spacer arrangement illustrated in Fig. 3. Sheet **16***a* is seen to be spaced from sheet **16***b* and the latter is similarly spaced from an insulating sheet **18** by a series of insulator knobs formed of buttons **20** with threaded stud portions extending from one side of each sheet through that sheet and held in place by a threaded insulating nut **22** on the opposite side of each sheet. These knobs are seen to alternate in the plane of the cross-section represented in Fig. 3, with a knob on each sheet being positioned in the space between knobs of the other sheet. The knobs similarly alternate in the plane perpendicular to the planes of the view and of the conductive sheets shown in the view, and this spacing is established throughout, even in the curved region of the U. It is by virtue of such dispersed insulating knobs that highly effective cooling is achieved with this sheet-conductor form of secondary. In use the transformer is disposed with the coil axes vertical, so that cooling can be accomplished by convection. Where multiple laminations are used for each sheet **16***a* and each sheet **16***b*, it is similarly advantageous for more efficient cooling and for reduction of eddy currents to use these knob type insulating spacers between laminations.

Fig. 4 illustrates a modification of the embodiment in Figs. 1 and 2, in respect to construction of low voltage windings. Corresponding numerals are employed here to designate parts corresponding to those of Figs. 1 and 2. In this case the outer U is not subdivided at its midpoint but extends continuously past the point **16***c* where a vertical terminal bar t_2 is joined to the copper sheet **16***a* directly. At the extremities of the U, the edges **16***e* of the sheets are joined together physically and to a vertically extending terminal bar. While eddy currents of higher level will naturally occur in this form of construction as compared to that of Figs. 1 and 2, this form of construction is simpler and is suitable for lower power applications.

Fig. 5 is a modification of the invention as applied to the interleaved type of transformer. In this embodiment, primary coils **10'** are split into balanced halves disposed at the upper and lower ends of legs **12'** of the transformer core, these core legs being interconnected by end portions **14'** of the core. A U-shaped secondary structure extends through both core windows **15'**, this secondary including outer conductor **16***a'* and inner conductor **16***b'* of construction exactly the same as that in Figs. 1 and 2, or Fig. 4. The secondary is seen to be disposed between two portions of the split primary winding on the center leg of the core. The details of mechanical support and the insulation of each of the windings from the other windings and from the core are omitted from the drawing as unnecessary to the clear understanding of the invention. It is immediately apparent, however, that the secondary structure in this interleaved transformer is remarkably simple in form and economical in respect to the weight of conductor that is required. The interconnection of the primary windings, from each section to the other of each phase and from each phase to the others, is readily feasible without obstruction from the secondary or the terminals thereof. The primary taps customarily provided in each section can readily be connected to selected taps of the other primary section of each phase without resort to special ducts or the like for such connections. While this interleaved transformer lacks some of the advantages of the concentric type in Figs. 1 to 4, it is nonetheless a highly desirable application of certain aspects of the invention.

This transformer has been described as a step-down transformer, in which the terms "primary" and "second-

ary" apply to the high- and low-voltage windings, respectively; and while the structure is customarily employed as a step-down unit, the low-voltage winding conceivably could serve as the input winding. The terms "primary" and "secondary" are accordingly used largely for reference to designate high- and low-voltage windings as they are customarily used, but these terms are not intended in their limited application to input and output connections.

Various modifications and adaptations of the fundamental aspects of this invention will be readily apparent to those skilled in the art from the disclosure of the specific embodiments above; and accordingly the present invention should not be restricted to the details illustrated but instead the appended claims should be broadly construed consistent with the spirit and scope of the invention.

What is claimed is:

1. A transformer including a magnetic core of the type having first, second and third core sections disposed side by side in the order named, and a pair of end sections interconnecting the respective ends of the side-by-side sections, first, second and third primary windings on said side-by-side core sections, respectively, and a secondary winding extending about three sides of said second primary winding and being open on the fourth side thereof, said secondary winding having a pair of terminal connections at one side of said magnetic core and having a third connection at the other side of said magnetic core.

2. A transformer including a magnetic core of the type having first, second and third core sections disposed side by side in the order named, and a pair of end sections interconnecting the respective ends of the side-by-side sections, first, second and third primary windings on said side-by-side core sections, respectively, and a secondary winding extending about three sides of said second primary winding and being open on the fourth side thereof, said secondary winding having a pair of terminal connections at one side of said magnetic core and having a third connection at the other side of said magnetic core, and a series of taps on each primary winding at axially distributed points, the taps on said second primary winding projecting at the side thereof left open by the secondary winding.

3. A transformer including a magnetic core of the type having first, second and third core sections disposed side by side in the order named, and a pair of end sections interconnecting the respective ends of the side-by-side sections, first, second and third primary windings on said side-by-side core sections, respectively, and a generally U-shaped secondary winding extending about three sides of said second primary winding, said secondary winding being formed of a pair of U-shaped coextensive conductors mutually insulated except at the extremities of the U.

4. A transformer including a magnetic core of the type having first, second and third core sections disposed side by side in the order named, and a pair of end sections interconnecting the respective ends of the side-by-side sections, first, second and third primary windings on said side-by-side core sections, respectively, and a generally U-shaped secondary winding extending about three sides of said second primary winding, and terminal connections to said secondary winding at the extremities of the U and at the midpoint thereof.

5. A transformer including a magnetic core of the type having first, second and third core sections disposed side by side in the order named, and a pair of end sections interconnecting the respective ends of the side-by-side sections, first, second and third primary windings on said side-by-side core sections, respectively, a generally U-shaped secondary winding extending about three sides of said second primary winding being open at the fourth side thereof, terminal connections to said secondary winding at the extremities of the U and at the midpoint thereof, and a series of taps on each primary winding at axially distributed points, the taps on said second primary winding projecting at the side thereof left open by the secondary winding.

6. A polyphase transformer including a magnetic core of the type having three side-by-side legs including a center leg between two outside legs and said three legs being interconnected at their ends and having a primary winding about each of the legs, said windings being interconnected to afford three-phase primary terminals, and an electrically conductive sheet of generally U-shaped contour extending about the center core leg and having three-phase terminal connections thereof.

7. A three-phase transformer having a magnetic core of the type having three side-by-side legs including a center leg between two outside legs and said three legs being interconnected at their ends and having a primary winding about each of the legs, said windings being interconnected to afford three-phase primary terminals, and an electrically conductive sheet of U-shaped contour extending about the central core leg, said sheet having a pair of terminals at the extremities of the U shape and at the midpoint thereof so as to afford three-phase secondary terminals.

8. A three-phase transformer having a magnetic core of the type having three side-by-side legs including a center leg between two outside legs and said three legs being interconnected at their ends and having a primary winding about each of the legs, said windings being interconnected to afford three-phase primary terminals, and an electrically conductive sheet of U-shaped contour extending about the central core leg, said sheet having a pair of terminals at the extremities of the U shape and at the midpoint thereof so as to afford three-phase secondary terminals, said primary windings being subdivided into spaced-apart portions, and said conductive sheet being interposed between the portions of the primary windings.

9. A three-phase transformer having a magnetic core of the type having three side-by-side legs including a center leg between two outside legs and said three legs being interconnected at their ends and having a primary winding about each of the legs, said windings being interconnected to afford three-phase primary terminals, and an electrically conductive sheet of U-shaped contour extending about the central core leg, a second conductive sheet of U-shaped contour coextensive with the first but spaced and insulated from the first mentioned U-shaped sheet except for respective connections at the extremities of the U shape, said connections constituting two of three secondary terminals, and a third terminal connected to one of said U-shaped sheets at the midpoint thereof.

10. A three-phase transformer including a magnetic core of the type having three side-by-side legs including a center leg between two outside legs and said three legs being interconnected at their ends and having a primary winding about each of the legs, said windings being interconnected to afford three-phase primary terminals, and a pair of mutually spaced electrically conductive sheets disposed one within the other extending only partway about the central core leg and joined along their axial edges to afford a pair of secondary terminals at one side of the magnetic core, and a third terminal extending axially along the midpoint of the outer one of said sheets at the other side of the magnetic core.

11. A three-phase transformer including a magnetic core of the type having three side-by-side legs including a center leg between two outside legs and said three legs being interconnected at their ends and having a primary winding about each of the legs, said windings being interconnected to afford three-phase primary terminals, and a conductive sheet of generally U-shaped contour extending about the central core leg, each of said primary windings having a series of taps distributed axially along the outer surface thereof, the taps of said central wind-

ing being disposed at the opening left by the secondary.

12. A three-phase transformer including a magnetic core of the type having three side-by-side legs including a center leg between two outside legs and said three legs being interconnected at their ends and having a primary winding about each of the legs including a central winding between the remaining two windings, said windings being interconnected to afford three-phase primary terminals, and a pair of mutually spaced electrically conductive sheets disposed one within the other about only three sides of said central core leg winding and joined along their axial edges to afford a pair of secondary terminals at one side of the magnetic core, and a third terminal extending axially along the midpoint of the outer one of said sheets on the other side of the magnetic core, each of said primary windings having a series of taps distributed axially along the outer surface thereof, the taps of said central core leg being disposed at the opening left by the secondary.

13. A three-phase transformer including a three-legged magnetic core formed to provide a pair of windows on opposite sides of a central leg, first and third primary windings each extending about one of the core legs and through one of said windows and a second primary winding about the central core leg and extending through both of said windows, and a generally U-shaped three-terminal secondary winding extending through both of said windows.

14. A three-phase transformer in accordance with claim 13, wherein said primary and secondary windings are concentric.

15. A three-phase transformer in accordance with claim 13, wherein said primary and secondary windings are interleaved.

16. A three-phase transformer in accordance with claim 13, wherein said secondary winding is formed of multiple electrically conductive sheets and wherein such sheets are mutually separated by insulating knobs each having enlarged portions on opposite faces of a sheet and the enlarged portions being joined together by a shank portion extending through the sheet.

17. In a transformer, a winding formed of multiple convolutions of curved conductive sheets spaced apart by knobs of insulation, each knob having an enlarged portion on opposite faces of a sheet and having an interconnecting portion extending through the sheet.

18. In a transformer, a winding formed of multiple convolutions of curved conductive sheets spaced apart by knobs of insulation, each knob having an enlarged portion on opposite faces of a sheet and having an interconnecting portion extending through the sheet, the knobs of each sheet being spaced apart and knobs of the opposed convolution of the winding being disposed in the spaces.

19. A transformer including a magnetic core of the type having first, second and third core sections disposed side by side in the order named and a pair of end sections interconnecting the respective ends of the side by side sections, first, second and third primary windings on said side by side core sections, respectively, and secondary winding means including a conductor extending from one side of the magnetic core to the opposite side only between the first and second core sections and having terminal connections means at the extremities thereof and a second conductor extending from one side of the magnetic core to the opposite side thereof only between the second and third core sections and having terminal connection means at the extremities thereof, the terminal connection means of said conductor and said second conductor at one side of the magnetic core being connected together so that said secondary winding means provides three terminals.

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